Journal of Infrastructure, Policy and Development 2024, 8(8), 4967.
https://doi.org/10.24294/jipd.v8i8.4967

Article

Investigating the impacts of COVID-19 on the built environment: The Fourth Industrial Revolution application's role via unexplored approach

Andrew Ebekozien[1,2,3,4,*], Mohamed Ahmed Hafez Ahmed[2], Wellington Didibhuku Thwala[5], Clinton Aigbavboa[1], Mohamad Shaharudin Samsurijan[4]

[1] Department of Construction Management and Quantity Surveying, University of Johannesburg, Johannesburg 2006, South Africa
[2] Department of Engineering, INTI International University, Nilai 71800, Malaysia
[3] Department of Quantity Surveying, Auchi Polytechnic, Auchi 312001, Nigeria
[4] Development Planning and Management, School of Social Sciences, Universiti Sains Malaysia, Gelugor 11800, Malaysia
[5] Faculty of Engineering, Built Environment and Information Technology, Walter Sisulu University, Eastern Cape 5660, South Africa
*** Corresponding author:** Andrew Ebekozien, ebekoandy45@yahoo.com

CITATION

Ebekozien A, Ahmed MAH, Thwala WD, et al. (2024). Investigating the impacts of COVID-19 on the built environment: The Fourth Industrial Revolution application's role via unexplored approach. Journal of Infrastructure, Policy and Development. 8(8): 4967. https://doi.org/10.24294/jipd.v8i8.4967

ARTICLE INFO

Received: 3 March 2024
Accepted: 25 March 2024
Available online: 23 August 2024

Abstract: Studies show that Fourth Industrial Revolution (4IR) technologies can enhance compliance with COVID-19 guidelines within the parties in the construction industry in the future and mitigate job loss. It implies that mitigating job loss improves the achievement of Sustainable Development Goal 1 (SDG 1) (eliminate poverty). There is a paucity of literature concerning 4IR technologies application and COVID-19 impact on South Africa's construction industry. Thus, this paper investigates the impacts of the pandemic on the sector and the roles of digital technologies in mitigating job loss in future pandemics. Data were collected via virtual semi-structured interviews. The participants proffered unexplored insights into the impact of the pandemic on the sector and the possible roles that 4IR technology can play in mitigating the spread of the virus within the sector. Findings show that the sector was hit, especially the low-income earners, threatens to achieve Goal 1, despite government institutions' intervention, such as economic support programmes, health and safety guidelines awareness, and medical facilities. Findings group the emerged impacts into health and safety, environmental, economic, productivity, social, and legal and insurance issues in South Africa. The study shows that technology can be advantageous to improving achieving Goal 1 in a pandemic era due to limited job loss.

Keywords: built environment; digital technology; feasible solutions; impacts; pandemic; SDG 1; South Africa

1. Introduction

In today's world, there are many surprises and worries. The current COVID-19 crisis ravaging the globe is one of such worries. The pandemic has interrupted various global sectors, including the built environment. The built environment sector is one of the catalysts and an integral part of every nation's economy. McKinsey Global Institute (2020) reported that globally, the sector receives not less than US$10 trillion annually on construction-related goods and services. Statista (2020) projection shows that the sector expenditures may reach US$14 trillion in 2025. Ebekozien (2021), and Ebekozien and Aigbavboa (2021), and Rehman et al. (2021) affirmed that the construction sector contributes to every nation's overall gross domestic product and create large job opportunities. In many developing countries, including South Africa, the sector is one of the largest sectors. Bogue (2018) asserted that despite the over $10 trillion per annum worth, one of the industry's challenges is the lax application of new digital technologies. Bogue (2018) emphasised that the built environment has been resistant to new advanced technologies such as blockchain technology, robotics, and big data. They belong to the 4th Industrial Revolution (4IR) (Tjahjono et al., 2017). The COVID-19 compounded issues for the built environment, especially in developing countries where 4IR technologies have not been encouraged (Ebekozien and Aigbavboa, 2021). COVID-19 may not exempt South Africa’s construction industry.

Recently, scholars such as Al-Yami and Sanni-Anibire (2021), Babatunde et al. (2021), Bogue (2018), Kim et al. (2020), Manda and Dhaou (2019), Nkosi et al. (2020), Oesterreich and Teuteberg (2016), Oke et al. (2021), Sutherland (2020), and Tahmasebinia et al. (2020), affirmed that the importance of 4IR application in the construction industry is on the increase. Ebekozien and Aigbavboa (2021) found that though the COVID-19 pandemic halted construction activities, developed countries where 4IR technologies have been encouraged could render some services. Ebekozien and Aigbavboa (2021) discovered that the negative impacts of the pandemic on the built environment are immeasurable, such as increased joblessness, and costs and time overruns. Government institutions, this includes international organisations (Centre for Disease Control and Prevention and World Health Organisation) and construction practitioners (Occupational Safety and Health Administration and Association of General Contractors), attempted to curb these impacts via various programmes and policies such as restricted movement, physical distancing, working from homes, among others (World Health Organisation, 2020). This control may be a threat to achieving Goal 1 in the construction industry. This is because the industry generates many jobs.

Many of the possible impacts of COVID-19 on the built environment may be lessened by utilising the benefit of the 4IR application, especially in developing countries. As previously identified by Bogue (2018) and Tjahjono et al. (2017), big data, robots, cobots, cloud computing, and artificial intelligence (AI) are some of the drivers of 4IR technologies. Sipior (2020) stated that AI is pertinent in fighting COVID-19 in various sectors, including the built environment. Since the COVID-19 outbreak, AI exploration and usage have increased together with many data analysis tools for planning and identifying locations with possible high outbreaks. This information is useful to site managers regarding deciding to shut down the site completely or not. AI usage in many developing countries faces several challenges. Many developing nations face inadequate basic infrastructure and digital technology hindrances (Ebekozien and Aigbavboa, 2021). These issues have not helped many developing countries, including South Africa, though South Africa is far better than many infrastructures and 4IR (Sutherland, 2020). Sutherland (2020) affirmed some challenges that can be addressed via feasible policies. These digitalised technologies may enhance COVID-19 rules and compliance across the sub-sectors of the construction industry. There is a paucity of studies concerning the significance of 4IR in South Africa’s construction industry during the COVID-19 era. Few studies in this area either addressed the 4IR as it relates to South Africa’s construction industry (Ayentimi and Burgess, 2019; Aghimien et al., 2020; Ocholla and Ocholla, 2020; Osunsanmi et al., 2020; Oke et al., 2021; Rapanyane and Sethole, 2020; Sutherland, 2020; Uleanya and Ke, 2019) or addressed COVID-19 as it relates to South Africa’s construction industry (Arndt et al., 2020; Amoah and Simpeh, 2021; Chitiga-Mabugu et al., 2021; Harinarain, 2020; Simpeh et al., 2021). However, Ebekozien and Aigbavboa (2021) attempted to address both issues in Nigeria's context, but their research did not focus on the impacts of COVID-19 on Nigeria's construction sector. A mechanism that can ensure minimal impact of job loss during a pandemic and improve achieving Goal 1 is germane. The study's motivation is to improve achieving Goal 1 even in a pandemic situation. Thus, this paper attempts to investigate the impacts of COVID-19 on the sector and the roles of digital technology in South Africa's built environment. The outcome is to mitigate poverty (SDG 1) via loss of jobs in future pandemic. The paper's objectives are:

- To investigate the perceived negative impacts of COVID-19 on South Africa's built environment sector.
- To explore how 4IR technologies can be used to mitigate the negative impacts of COVID-19 and possible future pandemics within the built environment sector to achieve Goal 1.

This paper focuses on the main research question—how can 4IR technologies be used to mitigate the negative impacts of COVID-19 in South Africa's built environment sector? The study's goal is to improve achieving Goal 1 even in a future pandemic situation before 2030 using 4IR technologies. The study comprised six sections. The current section focuses on the background and part of the study's motivation. This includes the study's objectives. The next section summarises empirical results focusing on COVID-19 and its impacts on the built environment sector. Also, the section reviewed the role of 4IR in the sector. The third section describes the data sources and the qualitative research method adopted. This was followed by presenting findings in a thematic pattern from the ten major participants and relating findings to previous research via discussion. Following the findings is the policy and recommendations section and the conclusion section.

2. Literature review

2.1. COVID-19 and its impacts on the built environment sector

The disastrous global impacts of the COVID-19 across all sectors are unquantifiable. The built environment sector was not spared, including manufacturing construction-related materials. At the time of submitting this manuscript (2 January 2024), over 773,119,173 COVID-19 cases have been reported, 13.59 billion total COVID-19 vaccine doses administered, and death is over 6,990,067 worldwide (WHO, 2023). Similarly, in South Africa, over 4,076,463 cases have been reported, death is over 102,595, and recovered is over 3,912,506 (Worldometer, 2024). The World Health Organisation (WHO) foreseen this outcome and, on 30 January 2020, declared COVID-19 as a Public Health Emergency of Global Concern and subsequently as a pandemic on 11 March 2020 (Ebekozien and Aigbavboa, 2021). Alharbi (2022), Ebekozien and Aigbavboa (2021), and Mbiba et al. (2022) affirmed that despite the preventive and control measures put in place by WHO and several government organisations, the short and long-term catastrophes caused by this pandemic on human lives and the economy are unimagined. The construction sector was not left out of these new safety measures, such as a minimum of six feet of physical distancing, regular handwashing procedures, and nose masking (Jagun et al., 2022; Simpeh et al., 2021).

Before the era of COVID-19, many companies' enforcement and implementation of operative health and safety management on construction sites, especially in developing countries, was a huge challenge (Ebekozien, 2021). Implementing the COVID-19 guidelines for many companies became a harder challenge (Agyekum et al., 2022; Alharbi, 2022; Avice, 2020; Ebekozien and Aigbavboa, 2021). In Malaysia, the lockdown affected property development sites and impacted staff, production costs, and project completion timelines. This has caused operational issues (Jagun et al., 2022). High cost of implementation is one issue that operators try to avoid. In Ghana (Agyekum et al., 2021) and Jordan (Bsisu, 2020) found that the pandemic adversely affected companies' source of funds. Coping with the extra cost connected with the pandemic safety guidelines during construction activities may become unfeasible, especially in countries where enforcement and implementations are lax. The lockdown across many countries with rising cases came with rules and regulations. These rules affected the construction activities, including the manufacturing section of construction-related materials.

Scholars across the globe, such as Alsharef et al. (2021), Agyekum et al. (2021), Bsisu (2020), Hatoum et al. (2021), Jallow et al. (2020) and Ogunnusi et al. (2020), found construction workers loss of jobs because of the lockdown leading to construction projects suspension, projects delayed because of contractual matters, project cost escalation, among others as the challenges being faced. Ebekozien and Aigbavboa (2021) in Nigeria and Simpeh et al. (2021) in Ghana found it more difficult to handle materials and tools/equipment on-site during the pandemic era. In the USA built environment, Alsharef et al. (2021) discovered delays and shortage of construction materials; material demands became higher than supply, delays in inspections and securing permits, inefficiency in production rate, price escalations, loss of revenue, payment interruptions, higher safety fears, rise in disputes and claims issues as identified impacts. The spreading of the virus may have hindered the tools/equipment and material handling sharing mechanism on construction sites (Ebekozien and Aigbavboa, 2021). Thus, the need to explore the advanced digital approach to mitigate this now and in the future. This is one of the justifications for this study. Apart from investigating the impacts, the paper explores how 4IR technologies can be used to reduce the spread of pandemics within South Africa's construction industry. Other developing nations-built environment sectors may adopt findings from this study.

In 2017, statistics showed that the built environment sector engages over 1.4 million persons and contributes about 3.9% to the GDP of South Africa (Simpeh and Amoah, 2021). Several studies (Arndt et al., 2020; Amoah and Simpeh, 2021; Chitiga-Mabugu et al., 2021, Simpeh et al., 2021) have worked in the direction of COVID-19 as it relates to the construction sector but not in the direction of investigating in-depth impacts of COVID-19 on South Africa's built environment sector. Arndt et al. (2020) worked on the pandemic's impact but lacked in-depth knowledge of the construction sector. It was an overview of the South African economy emphasising secondary data. Arndt et al. (2020) found that persistent effects of the pandemic that is the climax with lockdown measures would bring worse outcomes for GDP. Chitiga-Mabugu et al.

(2021) found significant evidence of a decline in economic growth and employment, leading to more households under the poverty line. The construction industry is not exempted. The government social grants intervention during the pandemic cushioned the poorest of the poor from further crisis (Chitiga-Mabugu et al., 2021). Amoah and Simpeh (2021) identified unawareness of COVID-19, inadequate supply of personal protective equipment by firm management, lax compliance, among others, as the challenges facing the enactment of the COVID-19 safety measure. They identified theft of PPEs provided by construction companies as one of the industry's challenges. Insecurity and site control or management enhances this issue. Simpeh and Amoah (2021) research focused on how the pandemic guidelines could be fused into companies' safety policies and found that many of them have included a section of the regulations into their safety policies. But a lot still needs to be done regarding the perceived negative impacts of COVID-19 on South Africa's built environment sector. The study intends to fill this part of the theoretical gaps. Thus, this research investigates the impacts of the pandemic and the roles of digital technologies in South Africa's built environment sector.

2.2. The role of 4th IR technologies

The construction industry cannot afford to be left behind in the global digitalisation of the various sectors. Digital technology has been evolving at a fast rate. The Fourth Industrial Revolution (4IR) technology describes the trend of increasing digital technology and automation in the built and manufacturing sectors (Davies and Sharp, 2014). Ocholla and Ocholla (2020) reported that Klaus Schwab first coined 4IR in 2016. One of the intentions is that 4IR will be "all-inclusive" and impact everything, including the construction industry. Ebekozien and Aigbavboa (2021) and Oesterreich and Teuteberg (2016) categorised key technologies and ideas in the context of 4IR into three clusters. They are smart factories (e.g., automation, robotics, and modularisation), simulation and modelling, and digitalisation and virtualisation. **Table 1** presents the summary of the concept of 4IR technologies as classified by Akinradewo et al. (2021), and Ebekozien and Aigbavboa (2021), Oesterreich and Teuteberg (2016) and their role.

In South Africa, President Cyril Ramaphosa's Government put the 4IR into the national economic strategy blueprint, with critics such as creating jobs (Sutherland, 2020). The significance of these key technologies in the built environment has become germane. This is because digital technology is developing at a very fast speed. The digitalised technologies may reduce the further spread of the pandemic. This industry is worth above $10 trillion yearly, as Bogue (2018) affirmed. The 4IR concept is not a new trend in the South African construction industry arena but is not about mitigating the spread of present and future pandemics. This is a component of the gaps that the paper intends to fill. Other sectors may adopt findings from this paper within the country and other countries' construction sectors. This will be one of the practical implications that strengthen the justification for this paper. Few studies addressed the 4IR related to South Africa's built environment. Evidence from the reviewed literature shows that this study is the pioneer regarding 4IR usage in the South African built environment to reduce the spread of the present and possible future pandemics in the sector. Ayentimi and Burgess (2019) focused on the region's prospects and constraints of the 4IR. They found that foreign organisations engaged in 4IR in the region dominated a few companies, including South Africa. Uleanya and Ke (2019) reviewed rural African communities' preparedness for the 4IR skill acquisition via formal education. They found that African countries are far beyond, and an absence of policies to create the platform for learning and skills to explore the 4IR. This was corroborated by Sutherland (2020), and it was found that poor quality infrastructure, failings in its education system, lax governance, and inadequate documentation of policy formulation, among others, contributed.

Table 1. Summary of the concept of 4IR technologies and their role (Akinradewo et al., 2021; Ebekozien and Aigbavboa, 2021; Oesterreich and Teuteberg, 2016).

S/N	Cluster	Key digital technologies	Role
1	Smart factory	Automation	Enhance prefabrication and offers great benefits to improve quality and safety while reducing waste and costs
		Robotics	Support the vision of smart construction
		Internet of things/internet of services	Enable the creation of virtual networks to support smart factory environment
		Cyber-physical systems/embedded systems	Real-time monitoring system to check the use of PPE during construction activities
		Modularisation/prefabrication	For prefabricated construction
2	Simulation and modelling	Building information modelling (BIM)	Planning and realisation of largescale infrastructure projects and it's an innovative technology to virtually design and manages construction projects
		Simulation tools/simulation models	Used for project planning, resource planning or project management in general.
		3D printing	Assists construction professionals the capability to design and evaluate failures or faults digitally at the early stage of the work.
		Augmented/virtual/mixed reality	Used to create a risk-free virtual learning and training environment, e.g. for construction safety training
3	Digitalisation and virtualisation	Cloud computing	Provides integrated services and access via the Internet. E.g. for cross-company collaboration on construction sites. This enables all project participants to access information from any communication device with Internet access
		Blockchain technology	Assists in financial management, contract management, supply chain management, and blockcahin-based BIM
		Big data	Assists to collect the data from all data-generating devices like BIM models, embedded sensors, machines and make them available to project participants
		Mobile computing	Use of mobile devices to support communication and collaboration during construction activities.
		Social media	An effective way to improve construction activities and used to coordinate different projects via a common platform as a network for connecting, interacting and information sharing among participants
		Digitalisation	This is used to create a digital value chain such as digital project data and information management or digitisation in general.

Aghimien et al. (2020) focused on the digitalisation of construction firms through partnering in South Africa. They found a gap in digital partnering among the construction firms and identified key hindrances affecting digital partnering. Ocholla and Ocholla (2020) focused on developing skills for 4IR usage. Also, organised supporting training programme available to achieve this goal. Osunsanmi et al. (2020)

evaluated construction practitioners' preparedness to use 4IR for construction projects. It was found that South African construction practitioners are willing to use 4IR technologies to execute construction projects, but the integration of these mechanisms into practice is low. The construction practitioners may have contributed to the low application of components such as cyber-physical systems, human-computer interaction, robotics, and the internet of things. Rapanyane and Sethole (2020) analysed the implications of the 4IR regarding South Africa's job creation for the youths. Rapanyane and Sethole (2020) exposed the realities and myths encompassing the 4IR concept. The role of 4IR in mitigating poverty (SDG 1) via loss of jobs in future pandemic cannot be over-emphasised based on the study's COVID-19 experience. A mechanism that can ensure minimal impact of job loss during pandemic and improve achieving Goal 1 is germane. The study's motivation is to improve achieving Goal 1 even in a future pandemic situation through 4IR technologies. The study argues that this is pertinent because there is a relationship between job loss and extreme poverty (Goal 1). Thus, measures that can mitigate job loss through 4IR technologies will mitigate extreme poverty (Goal 1).

3. Research methodology

This research is exploratory and phenomenological. Garcia and Gluesing (2013) affirmed that this research method offers an appropriate method for dealing with the research context. Given the new and unexplored approach of the study content (perceived impacts of COVID-19 on South Africa's built environment and ways the 4IR technologies can mitigate the crisis within the sector), this approach is suitable. This is in line with Harinarain (2020), who adopted a qualitative research design to investigate COVID-19 lockdown in the construction sector in South Africa. The current study explored 4IR role in the current and future pandemics in South Africa and selected 13 semi-structured virtual interviews from construction companies' management staff, government agency construction-related management staff, information technology experts, academicians, and construction consulting firms. This is because semi-structured interviews allow data gathering from well-informed interviewees with work experience (Creswell and Creswell, 2018). Thematic analysis was adopted for the collected data, and saturation was achieved at the 10th interview. Only the interviews that achieved saturation were reported, as presented in **Table 2**. The research saturation was established when there was no evidence of 'new concept or further theoretical perceptions from the ongoing in-depth interviews. The investigators utilised their contextual insights in analysing and interpreting the data (Thorne, 2020). Utilising this method to establish saturation has added to the body of knowledge. A virtual interview was adopted because of the COVID-19 protocol guidelines. **Table 2** shows the interviewees' years of experience, position, and a brief job description. The post of those interviewed shows they are well-informed concerning the South African construction industry, COVID-19, and 4IR matters. Appendix shows the participant invitation letter and the semi-structured main questions sample.

Table 2. Summary of participants' description.

ID	Interviewee rank	Years of experience	Brief job description
P1	Quantity Surveyor	5 years	Construction company
P2	Chief Director	19 years	Construction company
P3	Quality Control Officer	6 years	Construction company
P4	Academician/Practice	14 years	Construction/ICT expert
P5	Academician/Practice	18 years	Construction consultant
P6	Academician/Practice	7 years	Construction consultant
P7	Resident Engineer	10 years	Construction consultant
P8	Director	10 years	I.T consultant
P9	Senior IT Expert	15 years	I.T consultant
P10	Ass. Project Manager	7 years	Government agency in construction-related
P11	Ass Project Manager	12 years	Government agency in construction-related
P12	Ass. Director	20 years	Government agency
P13	Academician/Dep Director, NGO firm during the COVID-19	22 years	Academic staff in one of the top South African universities

The study adopted purposive and snowball sampling techniques. For the purposive sampling technique, the focus is on selecting the interviewees. Next was the snowball sampling to accomplish saturation and a good representation of the study population, as opined by Boddy (2016) and Teddlie and Tashakkori (2010). The purpose is to establish the participant's readiness to participate, ease of inaccessibility, and experience regarding the subject matter. The researchers introduced the snowball technique when it was difficult to access participants to participate in the study. With the assistants of some participants, the researchers were able to reach out to other participants. Boddy (2016) affirmed that saturation is the key direction to end data collection for qualitative research. A similar approach was adopted by Jallow et al. (2020) to examine the impact of the pandemic on the UK-built environment sector and conducted only five semi-structured interviews against hitting saturation and good representation with ten participants in this study. The snowball sampling technique was employed because it is a type of sampling technique that permits researchers to access more interviewees through the participant's support (Creswell and Creswell, 2018). The collected data were coded (Aigbavboa et al., 2023a, 2023b; Corbin and Strauss, 2015; Ebekozien, 2020a, 2020b). WhatsApp video and Zoom were used to conduct the virtual interviews and lasted between 40 and 55 min.

In creating the codes, the study used thematic analysis (Aigbavboa et al., 2023a, 2023b; Ibrahim et al., 2022). The collected data were manually analysed, and findings were presented. The ten interview transcripts were read multiple times among the study's investigators to capture the interviewees' thoughts concerning the phenomenon. This aligned with Ebekozien and Aigbavboa (2021), that used the same approach to develop the initial coding scheme for their work. The first phase consists of coding the transcripts and then classifying the codes. The second phase involves using the categories from the first phase to re-read the transcript and discover the concepts (Jaafar et al., 2021). The researchers employed researcher reflexivity, triangulation, and member checking as the validity approaches to the collected data

(Creswell and Creswell, 2018). The research employed attribute, themeing, invivo, and narrative coding techniques (Corbin and Strauss, 2015). From the coding, 123 codes emerged. From the emerged 123 codes (such as digitalisation, advanced technology, lockdown, unemployment, high construction cost, increased poverty, inflation, movement restriction, lax standards, among others), nine categories (such as legal issues, environmental issues, financial issues, productivity issues, health and safety issues, the impact of COVID-19 on the built environment, the role of 4IR, among others) were developed and finally, two themes emerged (perceived negative impacts of COVID-19 on South Africa's built environment and ways the 4IR technologies can mitigate COVID-19 within the built environment).

4. Results and discussion

The impact of ongoing COVID-19 on the South African built environment and the possible roles that 4IR technologies can play to reduce the pandemic spread is one area with a paucity of literature in the South African context.

4.1. Theme one: Perceived negative impacts of COVID-19

Theme One offers a platform for the engaged experts to highlight key early impacts of the pandemic on the South African built environment. Findings across the board agree that the built environment is one of the worst-hit sectors. The sector has a vibrant supply chain that affects other sectors of the economy. One germane point which emerges from Theme One is the classification of the highlighted impacts into six main classes. They are productivity, economic, health and safety, environmental, social, legal, and insurance issues, as presented in **Table 3**. Some of the components are interrelated. The impacts were unprecedented, and the sector was not expecting it. This is a threat to SDGs 1 and 11 and may be hindrance to achieving them.

Table 3. Emerged perceived negative impacts and their components.

S/Nos	Category	Perceived impacts of the pandemic on South African construction industry	Source
1	Productivity issues	Low productivity	Majority
		Suspension of construction activities	Majority
		Difficulty in sharing materials and tools/equipment	P3
		Time overrun	Majority
		Workforce shortage because of migrant restriction	P3
		Interruption of project planning and scheduling	P3
		Emergences of new technologies	P4
		Practices to deal with absenteeism	P3
		Practices to deal with construction backlog of orders	P2
		Supply chain disruption leading to scarcity	P3
		Materials and equipment shortages	P3
2	Economic issues	Finances of companies in the industry hit hard (cash flow issues)	Majority
		Liquidity challenge (working capital affected)	Majority
		Increase the cost of the health and safety protocol in the industry	P1
		Construction cost, equipment, and materials escalate	Majority

Table 3. (*Continued*).

S/Nos	Category	Perceived impacts of the pandemic on South African construction industry	Source
2	Economic issues	Increase low-income households in the industry under the poverty line	P5
		Cost overruns	Majority
		Supply-side shocks that escalate the material prices	P1
		Implication of increased bankruptcy	P3
		Reduction in revenue	Majority
3	Health and safety issues	Increased lapses in the management of health and safety in the industry because of the new health and safety practices	Majority
		Inadequate supply of PPE	P8
		Adapting to new guidelines are difficult for field workers	P8
		Increase risk of the sector's employees	Majority
		Anxiety leading to fatigue and poor mental health of employees	P3
		Increases the inadequate existing safety interventions	P8
		Inadequacy of health and safety management of many firms revealed	P8
4	Environmental issues	Construction projects abandoned	Majority
		Construction project delays	Majority
		Communication challenges because of movement restriction	Majority
		Physical distancing and face mask-wearing	Majority
		Travel restrictions	Majority
5	Social issues	Stress and increased level of depression resulting from the lockdown and travel ban	P3 and P6
		Confusion and anxiety in employee's behaviour	P3
		High loss of jobs	Majority
6	Legal and insurance issues	Increased legal issues of terminated employees without the benefit	Majority
		Implications on contractual obligations for construction projects (force majeure clauses)	Majority
		New contract negotiation practices	P2
		Delay permits	Majority
		Approval and inspections	P10
		Emergence of mergers and acquisitions	P7
		Possible changes in notice requirements because of the crisis	P8
		Potential change in insurance policies	P5
		Practices to deal with lien claims arising from the crisis	P2

4.1.1. Productivity issues

Participant P4, a Project Manager, says: "*…the impact of the pandemic in the context of South African construction industry was unforeseeable and generated uncontrollable negative outcomes beyond the reasonability of any party. But something can still be done to curtain the virus within and outside the industry…*"

Participant P3 says: "*…since South Africa's construction industry depends on imported materials and migrant workers from Lesotho and Zimbabwe, the logistics to transport these* materials *and men to various construction sites were badly affected. Moreover, the migrants that travelled before the pandemic breakout could not return because of the close of borders and movement restriction…*"

Results agree with Moroz et al. (2020) and Oni et al. (2020). A World Bank

Working Paper 8 that remittances flow to Lesotho and Zimbabwe, where remittances represent 15.7% and 8% of GDP, respectively, were negatively affected in South Africa. Moroz et al. (2020) affirmed that migrants losing their employment has extra negative impacts on the migrants' families and extended families in their home nations. Oni et al. (2020) found that COVID-19 control measures disrupted routine activities and affected physical activity behaviours. The World Bank (2020a) collaborated that the drop in earnings from their employment because of the pandemic outbreak will result in weighty declines in the remittances that families throughout the globe rely on to make ends meet and to make investments in human capital and businesses and estimated to be about 20% in 2020. This is not favourable to SDGs like Goals 1 and 11.

4.1.2. Economic issues

Participant P8 says: "*…enhanced poverty, no jobs, construction sites are closed, fewer tenders are issued or late award of projects, contractors are bankrupt due to the COVID, construction* site *stoppages, construction cost overruns due to site-shut down, etc. were the major negative impacts on the sector from my observation and experience…*"

Project delays, cost over-run, labour shortage, economic shrinkage, and high unemployment, among others, were identified by Participant P2 as the perceived negative impacts on the South African built environment. The COVID-19 to the construction sector cannot be quantified. Findings agree with Jagun et al. (2022), and it was found that the lockdown affected property development sites and impacted staff, production costs, and project completion timelines.

4.1.3. Health and safety issues

Most participants are concerned with the rising cases in the current third wave of the "Delta variant," a type of COVID-19.

Participant 8 says, "*…the fight against this deadly virus should be all-inclusive. The stakeholders should not wait only for the South African Government to mitigate or curb the spread when some of us have refused to do the needful. Before this third wave, there were* allegations *that many personnel, mostly junior staff did not observe physical distancing and face mask covers despite the mask mandate by the government. Many construction sites and factories do not have safety officers to enforce compliance. Also, there is inadequate disinfectant within the workplaces…*"

Findings agree with Amoah and Simpeh (2021). It was discovered that the inadequate supply of personal protective equipment by South Africa's construction companies contributed to the implementation of the COVID-19 safety measures and guidelines.

4.1.4. Environmental issues

As identified by Participant P3, travel restrictions hindered logistics and, by extension, enhanced many construction projects delays during the pandemic's first and second waves.

Participant P1 says, "*…site inspection and evaluation, including communication, was hindered because of the movement restriction except for those on critical assignment…*"

Findings agree with Agyekum et al. (2022) and Harinarain (2020). Harinarain (2020) discovered that the lockdown forced workers to work differently. Apart from the financial implications of the pandemic, there was greater consequence regarding the psychological impact on the workers. Agyekum et al. (2022) found delays in payments and increased material costs because of the border closure.

4.1.5. Social issues

Findings show that fear of the unknown increased during the pandemic as many lost jobs daily. Participants P3 and P6 opine that stress and depression increased during the lockdown. Findings agree with Ebekozien and Aigbavboa (2021) and Gamil and Alhagar (2020), and it was found that suspension of construction projects due to movements restriction and hike-up in the supply chain, workforce shortage because of construction projects suspension, time overrun because of the lockdown, and financial crisis impact triggered by the lacuna in the cash flow were identified as the most severe impacts of the pandemic on the built environment in developing countries such as South Africa.

4.1.6. Legal and insurance issues

Findings show an increase in employees' termination without benefits, delay permits, and changes in insurance policies. Findings agree with Alharbi (2022), and it was found that the COVID-19 crisis threatened several expectations.

Participant P8 says, "*…there was an unplanned suspension of construction activities* because *of no fault of either party. The outcomes were time and cost overruns, cash flow issues, liquidity challenges, materials and labour costs escalating, and reduction in revenue…*"

Participant P8 identified an increased risk to the sector's employees and increased legal issues of terminated employees without benefits as potential issues during the pandemic.

4.2. Theme two: Ways 4IR technologies mitigate COVID-19

Theme Two offers the interviewees a platform to investigate how digital technology can be adopted to reduce COVID-19 impact and future pandemics on the South African construction industry. This includes measures to mitigate job loss and eliminate poverty through 4IR technologies application in future pandemics and improves the achievement of Goal 1. The paper modified Ebekozien and Aigbavboa (2021) and Oesterreich and Teuteberg (2016) 4IR technologies in the built environment sector classification. They are smart construction, simulation and modelling, and virtualisation, as presented in **Table 4**. Findings across the board agree that improved digitalisation of the South African built environment would have mitigated the spread of the pandemic within the sector with the exemption of Participant P4, which says, "*…to a reasonable extent, yes…*".

Table 4. Summary of the ways 4IR technologies can prevent/mitigate COVID-19 spread.

S/N	Group	Digital technologies	Ways 4IR can prevent/mitigate COVID-19
1	Smart construction	Automation and prefabrication	Off-site prefabrication construction will reduce workers on-site and enhances project delivery value via an automation mechanism. Mechanism to improve labourers value via critical and generic skills development should be in phases to avoid increased unemployment (Majority).
		Robotics	It will promote smart construction, but labourers should be trained to upgrade their skills and improve their value (Majority).
		Internet of things/internet of services	Virtual networking is key in smart construction and will enhance physical distancing if well implemented (P3, P4, P7, P8, and P10).
		Cyber-physical systems/embedded systems	Strict compliance to PPE usage is key to mitigating the spread of the pandemic and the real-time monitoring system can be employed to achieve this task (P3, P4, P7, and P8).
2	Simulation and modelling	Building information modelling	For large construction entities, infrastructure projects planning is key. BIM can enhance the task with some innovation and manage multiple sites at the same time. Also, the technology promotes less physical contact of parties (Majority).
3	Virtualisation	Cloud computing	This technology enhances physical distancing and encourages integrated services and access of information by the parties via the Internet (Majority).
		Mobile computing	Mobile computing has reduced physical site meetings drastically, enhances communication and collaboration, and by extension, promotes physical distancing on construction sites (Majority).

4.2.1. Smart construction

Findings show that many digital technologies are used in some developed countries' construction industry. They could enhance the regulations and guidelines of international health organisations such as the World Health Organisation regarding the prevention and mitigation of COVID-19 spread and future contagious pandemics with similar attributes like the COVID-19.

Viewpoint from Participant P9 says, "…*the industry still requires humans due to its nature. However, if it was fully digitalised, it would have mitigated the spread to a considerable extent for a human-intensive industry. This is because it would have reduced the* human *contact, thus, enhancing the enforcement of physical distancing as one of the key guidelines from the international health organisation and the South African Health Ministry*…"

This agrees with Alsharef et al. (2021), Ogunnusi et al. (2020), and Rehman et al. (2021). Ogunnusi et al. (2020) found that the pandemic can be mitigated via enhanced digital technology. For example, virtual digitalisation for continuity of meetings on some construction projects was encouraged and used. Whilst robotics can enable productivity levels to be kept at satisfactory levels or above (Participant P4).

Participant P1 says, "…*its high time South African construction practitioners embraced digital technologies as obtainable in some developed countries construction industry such as* telework*, automation, robotics, cloud-based applications, integrated reporting and management methods, and so forth. These technologies increase the reliance on offsite construction and methods using artificial intelligence, machine learning, computer vision, data analytics, and computer applications to ensure compliance with the different requirements. The technology helps detect compliance to physical distancing and face mask of workers*…"

Findings from this study show that participants agree that 4IR technologies can mitigate the pandemic and future pandemics. Still, using 4IR should come in phases via a national policy to upgrade the workers involved in direct labour for skilled operations. Also, findings suggest adequate training of practitioners and skills development. The government has a key role to play in this respect. The government should be the key driver of the 4IR campaign. The proposed framework for incentive programmes to stimulate construction contractors and consultancy teams to use digital technology in the industry should be policy-driven with the political will to push it.

4.2.2. Simulation and modelling

Participant P3 says, "*…I am one of the advocates of digital technology in the construction industry. Still, we should prioritise national policy regarding the existing labour-intensive construction mechanism being operated in South Africa to reduce unemployment. Bring in 4IR should be in phases while those engaged for direct labour now will need to upgrade to higher skill and improve for human value…*"

Thus, efficiency related to Information and Communication Technology (ICT) and efficiency over-inclusiveness should be evaluated in taking this decision in South Africa's context. Rehman et al. (2021) recommended the digitisation of processes as one of the ways the construction industry can adversely impact the virus. Findings show that digitalisation will help the industry regarding administrative issues. Examples of such issues are offsite issuing of instructions and work monitoring, virtual project meetings, digital construction against conventional methods, adoption of alternative technology, and non-reliance on human labour. The economic footprint of South Africa should be taken into consideration. Participant P3 emphasises this aspect because the labour-intensive construction policy concept is to provide jobs. Assaad and El-Adaway (2021) suggested that research should be conducted on how modelling, optimisation, and simulation of construction activities can mitigate the spread of the pandemic. This is one of the justifications for this paper.

Participant P2 says, "*…BIM and simulation and modelling are among the central technologies that have recorded tremendous success in the construction manufacturing environment…*"

Though the usage is still low, the perceived causes are not within the scope of this paper. Results agree with Al-Yami and Sanni-Anibire (2021), Babatunde et al. (2021) and Oesterreich and Teuteberg (2016). Oesterreich and Teuteberg (2016) discovered that most of the top literature regarding 4IR described simulation and modelling as relevant concepts to accomplish the growing complexity of manufacturing procedures and enhance them by setting situations and mitigating risks. Also, findings reveal other drivers that can mitigate COVID-19 within the sector, such as augmented reality (AR), cyber-physical systems, product-lifecycle-management (PLM), robotics, automation, mobile computing, and radio-frequency identification (RFID), among others. The augmented reality and drone technology could be used for inspections and scheduling of workers to tasks (Participant P10). From a health and safety point of view, this technique will be better for the industry.

4.2.3. Virtualisation

Social distancing is one of the key guidelines to mitigate or prevent the spread of COVID-19 pandemic, as recommended by the World Health Organisation (2020). Findings show that cloud computing, a virtualisation component, can enhance social distancing and encourage integrated services within the project's team members.

Participant P9 says, "*…cloud computing will reduce physical site meetings and enhances network within the team members…*" Findings agree with Oesterreich and Teuteberg (2016), and it was found that cloud computers would allow team members to access information from any communication platform for coordinating, viewing, dissemination, and collaborating on projects.

5. Policy and recommendations

Evidence shows that the relevance of 4IR technologies applications is germane to the growth of the construction industry and can enhance integrated project delivery. Still, many of the technologies used are low in South Africa's context. The perceived negative impacts of the COVID-19 pandemic and their components on South Africa's construction industry were grouped into six. Findings show that most digital technology can be advantageous to promote COVID-19 compliance if well utilised but presently, usage is low. For improved usage of these technologies in South Africa's construction industry and enhance job security to eliminate poverty (SDG 1) during future pandemic, the study proposed the following feasible policies as part of the paper's implications. First, the South African Government should set up an institutional framework to review the existing Labour-Intensive-Construction (LIC) policy. This is germane because 4IR will reduce labour forces on sites. Thus, the framework should work out the modalities to redefine human drivers and upgrade to higher critical and generic skills via training. The training focus may be directed towards skills in operating some of this hardware, such as operating the robotics. This recommendation will form part of the practical implications.

Second, knowing that digital technology will improve materials and labour productivity with a higher level of compliance to the safety guidelines regarding pandemics, emphasis should be on all-inclusiveness and efficiency concerning ICT. As a major client, South Africa's Government needs to priorities its needs. This is because South African national policy encourages labour-intensive strategies to mitigate unemployment. Thus, to address the increase in unemployment resulting from 4IR technologies applications in the construction industry, education, and training of the low-income earners to improve human value cannot be over-emphasised. Also, the proposed institutional framework should be designed so that the full implementation of the 4IR technologies in the industry should be in phases via construction incentivisation to encourage construction practitioners, especially construction companies, to accept and implement these applications. During these phases, there would have been substantive skills development from the labourers to fix into other sub-sections of the industry. The outcome may enhance integrated project delivery via collaboration and mitigate the fear associated with higher unemployment by adopting 4IR in developing nations' settings. This aspect of the proposal should be further investigated.

The study has established theoretical and methodological gaps. There is unsatisfactory literature on how 4IR technologies can mitigate the spread of COVID-19 in South Africa's built environment sector. For the methodological gap, few studies have employed a qualitative research design, such as Ebekozien and Aigbavboa (2021); none in South Africa investigate issues connected with COVID-19 and 4IR roles in the built environment. From a theoretical perspective, this study evaluates the pertinent role of 4IR technologies in South Africa's built environment pandemic era. Theoretically, the paper intends to enhance researchers' knowledge of 4IR technologies, COVID-19, and the built environment (Ebekozien and Aigbavboa, 2021). These implications add to the findings by Ebekozien and Aigbavboa (2021). Ebekozien and Aigbavboa (2021) analysed the role of 4IR technologies in Nigerian construction site recovery in the post-COVID-19 era. Thus, the study contributes to the studies pioneering 4IR role in mitigating COVID-19 and future pandemics in the built environment.

6. Conclusion

This study explored the perceived negative impacts of the COVID-19 pandemic and how 4IR technologies can be used to mitigate the spread of COVID-19 and future pandemics within South Africa's construction industry. The outcome is to mitigate job loss (eliminate poverty—SDG 1) in future pandemics. A mechanism that can ensure minimal impact of job loss during a pandemic and improve achieving Goal 1 in the future is germane. The study's motivation is to improve achieving Goal 1 even in a pandemic situation in the future. Findings show that the built environment sector is one of the worse hit sectors in South Africa. As a result, 44 perceived impacts emerged from the virtual interviews conducted with ten participants. The issues were categorised into six groups (health and safety issues, environmental issues, economic issues, productivity issues, social issues, and legal and insurance issues). Also, findings show that 4IR technologies can prevent or reduce the spread of COVID-19 in the built environment sector in South Africa's context. Various technologies were identified, and how they can mitigate or prevent the spread of COVID-19 in the built environment were highlighted. Presently, the usage of 4IR technologies in the South African construction industry is low. This may be one of the reasons for the insignificant mitigation impacts. For improved 4IR technologies applications in the sector, the South African Government should set up an institutional framework to review the pros and cons of Labour-Intensive-Construction (LIC) policy and 4IR technologies application in the construction industry policy. This is germane because 4IR will reduce site labour forces and improve productivity.

The main contribution of this study is to provide key stakeholders and policymakers with detailed possible perceived early negative impacts of COVID-19 on the built environment. Also, to mitigate poverty (SDG 1) via loss of jobs in future pandemic and how the 4IR technologies applications can play a great role in mitigating the spread within the industry in developing countries, using South Africa as a case study. Results and recommendations from this research might benefit policymakers, researchers, and construction practitioners to start looking beyond Labour-Intensive-Construction (LIC) Policy in the construction sector for more productivity and higher critical and generic skills development of human value. This is a component of defined human drivers for efficiency and all-inclusiveness. The above are components of the researchers' contributions and drivers to enhance the South African construction industry for better performance and productivity of goods and services delivery. The key limitation of this study is that ten participants were covered during the virtual interviews. Though reflecting the opinions of a relatively small study section, results are generalisable because of their expertise, years of experience, and ranks. Moreover, the study achieved saturation. For validation purposes in the future, the study suggests an exploratory sequential mixed research design. This aligned with Creswell and Creswell (2018) and Ebekozien et al. (2019). They avowed that exploratory sequential mixed research design aids scholars in validating the qualitative findings. Also, it allows for expanded coverage and increases the study's generalisability findings. This is lacking in previous studies regarding COVID-19 and the 4IR technologies in South Africa's built environment sector, thus, providing a methodological gap. Also, the perceived constructs that emerged could be validated in future studies.

Author contributions: Conceptualization, AE, MAHA, WDT, CA and MSS; methodology, AE, MAHA and CA; software, AE, CA and MSS; validation, AE and CA; formal analysis, AE, MAHA, WDT, CA and MSS; investigation, AE, MAHA, WDT and CA; data curation, AE and CA; writing—original draft preparation, AE, MAHA, WDT, CA and MSS; writing—review and editing, AE, MAHA, WDT, CA and MSS. visualization, AE, MAHA, WDT, CA and MSS; supervision, AE, MAHA, WDT, CA and MSS; project Administration, AE, MAHA, WDT, CA and MSS; funding acquisition, AE, MAHA, CA and MSS. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by School of Social Sciences, Universiti Sains Malaysia, George Town, Malaysia and Faculty of Engineering and the Built Environment and CIDB Centre of Excellence, University of Johannesburg, Johannesburg, South Africa, grant number 05-35-061890, and the APC was funded by INTI International University, Nilai, Malaysia.

Acknowledgments: Special thanks to the participants for providing scholarly contributions to enhance the findings of this study. The authors appreciate the comments, suggestions, and recommendations provided by the anonymous reviewers, which honed and strengthened the quality of this manuscript during the blind peer-review process.

Conflict of interest: The authors declare no conflict of interest.

References

Aghimien, D., Aigbavboa, C., Aghimien, L., et al. (2020). Making a case for 3D printing for housing delivery in South Africa. International Journal of Housing Markets and Analysis, 13(4), 565–581. https://doi.org/10.1108/ijhma-11-2019-0111

Agyekum, K., Kukah, A. S., & Amudjie, J. (2021). The impact of COVID-19 on the construction industry in Ghana: the case of some selected firms. Journal of Engineering, Design and Technology, 20(1), 222–244. https://doi.org/10.1108/jedt-11-2020-0476

Aigbavboa, C., Addo, L., Ebekozien, A., et al. (2023a). Developing a framework for effective institutional management of Ghana's urban water supply. International Journal of Building Pathology and Adaptation.

Aigbavboa, C., Ebekozien, A., & Mkhize, N. (2023b). A qualitative approach to investigate governance challenges facing South African airlines in The Fourth Industrial Revolution technologies era. Social Responsibility Journal, 19(8), 1507–1520.

Akinradewo, O., Aigbavboa, C., Oke. A., & Mthimunye, I. (2021). Applications of blockchain technology in the construction industry. In: Advances in creativity, innovation, entrepreneurship and communication of design, AHFE 2021. Lecture notes in Networks and systems. Cham.

Alharbi, R. (2022). An appraisal of the early impact of COVID-19 on affordable housing finance in Saudi Arabia's Vision 2030.

International Journal of Building Pathology and Adaptation. https://doi.org/10.1108/ijbpa-12-2021-0169

Alsharef, A., Banerjee, S., Uddin, S. M. J., et al. (2021). Early Impacts of the COVID-19 Pandemic on the United States Construction Industry. International Journal of Environmental Research and Public Health, 18(4), 1559. https://doi.org/10.3390/ijerph18041559

Al-Yami, A., & Sanni-Anibire, M. O. (2019). BIM in the Saudi Arabian construction industry: state of the art, benefit and barriers. International Journal of Building Pathology and Adaptation, 39(1), 33–47. https://doi.org/10.1108/ijbpa-08-2018-0065

Amoah, C., & Simpeh, F. (2021). Implementation challenges of COVID-19 safety measures at construction sites in South Africa. Journal of Facilities Management, 19(1), 111–128. https://doi.org/10.1108/jfm-08-2020-0061

Arndt, C., Davies, R., Gabriel, S., et al. (2020). Impact of COVID-19 on the South African economy: An initial analysis. SA-TIED Working Paper.

Assaad, R., & El-adaway, I. H. (2021). Guidelines for responding to COVID-19 pandemic: Best practices, impacts, and future research directions. Journal of Management in Engineering, 37(3), 1–18.

Avice, T. (2020). COVID-19: Lessons from a construction site, can we apply one industry safety protocol to another? Journal of Pediatric Rehabilitation Medicine, 13(3), 433–437. https://doi.org/10.3233/prm-200808

Ayentimi, D. T., & Burgess, J. (2019). Is The Fourth Industrial Revolution relevant to sub-Sahara Africa? Technology Analysis & Strategic Management, 31(6), 641–652. https://doi.org/10.1080/09537325.2018.1542129

Babatunde, S. O., Udeaja, C., & Adekunle, A. O. (2021). Barriers to BIM implementation and ways forward to improve its adoption in the Nigerian AEC firms. International Journal of Building Pathology and Adaptation, 39(1), 48–71. https://doi.org/10.1108/IJBPA-05-2019-0047

Black, B. (2020a). Pandemic planning for the construction industry—A guide. Alberta Construction Association.

Black B. (2020b). Pandemic planning for the construction industry—A guide. Calgary Construction Association.

Bogue, R. (2018). What are the prospects for robots in the construction industry? Industrial Robot: An International Journal, 45(1), 1–6. https://doi.org/10.1108/ir-11-2017-0194

Bsisu, K. A. D. (2020). The Impact of COVID-19 Pandemic on Jordanian Civil Engineers and Construction Industry. International Journal of Engineering Research and Technology, 13(5), 828. https://doi.org/10.37624/ijert/13.5.2020.828-830

Chitiga-Mabugu, M., Henseler, M., Mabugu, R., et al. (2020). Economic and Distributional Impact of COVID-19: Evidence from Macro-Micro Modelling of the South African Economy. South African Journal of Economics, 89(1), 82–94. https://doi.org/10.1111/saje.12275

Corbin, J., & Strauss, A. (2015). Basics of qualitative research: Techniques and procedures for developing grounded theory, 4th ed. Sage.

Creswell, J. W., & Creswell, D. J. (2018). Research design: Qualitative, quantitative, and mixed methods approaches, 5th ed. Sage.

Davies, A., & Sharp, D. (2014). RICS Strategic Facilities Management. Case Studies, International Workplace.

Ebekozien, A. (2020a). Corrupt acts in the Nigerian construction industry: is the ruling party fighting corruption? Journal of Contemporary African Studies, 38(3), 348–365. https://doi.org/10.1080/02589001.2020.1758304

Ebekozien, A. (2020b). Community participation in affordable housing provision in developing cities: A study of Nigerian cities. Journal of Human Behavior in the Social Environment, 30(7), 918–935. https://doi.org/10.1080/10911359.2020.1772164

Ebekozien, A. (2021). Construction companies' compliance to personal protective equipment on junior staff in Nigeria: issues and solutions. International Journal of Building Pathology and Adaptation, 40(4), 481–498. https://doi.org/10.1108/ijbpa-08-2020-0067

Ebekozien, A., Abdul-Aziz, A. R., & Jaafar, M. (2019). Housing finance inaccessibility for low-income earners in Malaysia: Factors and solutions. Habitat International, 87, 27–35. https://doi.org/10.1016/j.habitatint.2019.03.009

Ebekozien, A., & Aigbavboa, C. (2021). COVID-19 recovery for the Nigerian construction sites: The role of The Fourth Industrial Revolution technologies. Sustainable Cities and Society, 69, 102803. https://doi.org/10.1016/j.scs.2021.102803

Gamil, Y., & Alhagar, A. (2020). The Impact of Pandemic Crisis on the Survival of Construction Industry: A Case of COVID-19. Mediterranean Journal of Social Sciences, 11(4), 122. https://doi.org/10.36941/mjss-2020-0047

Garcia, D., & Gluesing, J. C. (2013). Qualitative research methods in international organizational change research. Journal of Organizational Change Management, 26(2), 423–444. https://doi.org/10.1108/09534811311328416

Harinarain, N. (2020). Despair during the COVID-19 lockdown for the South African construction industry. Journal of

Construction, 13(1), 52–63.
Hatoum, B. M., Faisal, A., Nassereddine, H., & Sarvari, H. (2021). Analysis of COVID-19 concerns raised by the construction workforce and development of mitigation practices. Frontiers in Built Environment, 7. https://doi.org/10.3389/fbuil.2021.688495
Ibrahim, F. S., Ebekozien, A., Khan, P., et al. (2022). Appraising Fourth Industrial Revolution technologies' role in the construction sector: How prepared is the construction consultants? Facilities, 40(7/8), 515–532.
Jaafar, M., Ebekozien, A., & Mohamad, D. (2021). Community participation in environmental sustainability: A case study of proposed Penang Hill Biosphere Reserve, Malaysia. Journal of Facilities Management.
Jagun, Z. T., Nyakuma, B. B., Daud, D., et al. (2022). Property development during the COVID-19 pandemic: challenges and outlook in Malaysia. Environmental Science and Pollution Research, 29(57), 85717–85726. https://doi.org/10.1007/s11356-021-18378-2
Jallow, H., Renukappa, S., & Suresh, S. (2020). The impact of COVID-19 outbreak on United Kingdom infrastructure sector. Smart and Sustainable Built Environment, 10(4), 581–593. https://doi.org/10.1108/sasbe-05-2020-0068
Kim, K., Lee, G., & Kim, S. (2020). A Study on the Application of Blockchain Technology in the Construction Industry. KSCE Journal of Civil Engineering, 24(9), 2561–2571. https://doi.org/10.1007/s12205-020-0188-x
Manda, M. I., & Ben Dhaou, S. (2019). Responding to the challenges and opportunities in the 4th Industrial revolution in developing countries. In: Proceedings of the 12th International Conference on Theory and Practice of Electronic Governance. https://doi.org/10.1145/3326365.3326398
Mbiba, B., Chireka, B., Kunonga, E., et al. (2020). At the deep end: COVID-19 experiences of Zimbabwean health and care workers in the United Kingdom. Journal of Migration and Health, 1–2, 100024. https://doi.org/10.1016/j.jmh.2020.100024
McKinsey global institute. (2020). Reinventing Construction, McKinsey Global Institute. Available online: https://www.mckinsey.com/_/media/McKinsey/Industries/Capital%20Projects%20and%20Infrastructure/Our%20Insights/Reinventing%20construction%20through%20a%20productivity%20revolution/MGIReinventing-Construction-In-Brief.ashx (accessed on 2 January 2024).
Moroz, H., Shrestha, M., & Testaverde, M. (2020). Potential Responses to the COVID-19 Outbreak in Support of Migrant Workers. World Bank, Washington, DC. https://doi.org/10.1596/33625
Nkosi, T., Aboginije, A., Mshwama, N., Thwala, W. (2020). Harnessing Fourth Industrial Revolution (4IR) for improving poor universities infrastructure in developing countries—A review. In: Proceedings of the International Conference on Industrial Engineering and Operations Management Dubai.
Ocholla, D. N., & Ocholla, L. (2020). Readiness of academic libraries in South Africa to research, teaching and learning support in the Fourth Industrial Revolution. Library Management, 41(6/7), 355–368. https://doi.org/10.1108/lm-04-2020-0067
Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. Computers in Industry, 83, 121–139. https://doi.org/10.1016/j.compind.2016.09.006
Ogunnusi, M., Hamma-Adama, M., Salman, H., Kouider, T. (2020). COVID-19 pandemic: The effects and prospects in the construction industry. International Journal of Real Estate Studies, 14(2),120–128.
Oke, A. E., Aigbavboa, C. O., Segun, S. S., et al. (2021). Sustainable Construction in the Era of the Fourth Industrial Revolution. Routledge. https://doi.org/10.1201/9781003179849
Oni, T., Micklesfield, L. K., Wadende, P., et al. (2020). Implications of COVID-19 control measures for diet and physical activity, and lessons for addressing other pandemics facing rapidly urbanising countries. Global Health Action, 13(1), 1810415. https://doi.org/10.1080/16549716.2020.1810415
Osunsanmi, T. O., Aigbavboa, C. O., Emmanuel Oke, A., et al. (2020). Appraisal of stakeholders' willingness to adopt construction 4.0 technologies for construction projects. Built Environment Project and Asset Management, 10(4), 547–565. https://doi.org/10.1108/bepam-12-2018-0159
Rapanyane, M. B., & Sethole, F. R. (2020). The rise of artificial intelligence and robots in the 4th Industrial Revolution: implications for future South African job creation. Contemporary Social Science, 15(4), 489–501. https://doi.org/10.1080/21582041.2020.1806346
Sami Ur Rehman, M., Shafiq, M. T., & Afzal, M. (2021). Impact of COVID-19 on project performance in the UAE construction industry. Journal of Engineering, Design and Technology, 20(1), 245–266. https://doi.org/10.1108/jedt-12-2020-0481
Saunders, M., Thornhill, A., Lewis, P. (2019). Research methods for business students. Pearson Education.

Schmidt, R., Möhring, M., Härting, R. C., et al. (2015). Industry 4.0—potentials for creating smart products: Empirical research results. Bus Information System, 27, 1–12.
Simpeh, F., & Amoah, C. (2021). COVID-19 guidelines incorporated in the health and safety management policies of construction firms. Journal of Engineering, Design and Technology, 20(1), 6–23. https://doi.org/10.1108/jedt-01-2021-0042
Simpeh, F., Bamfo-Agyei, E., & Amoah, C. (2021). Barriers to the implementation of COVID-19 safety regulations: Insight from Ghanaian construction sites. Journal of Engineering Design and Technology.
Sipior, J. C. (2020). Considerations for development and use of AI in response to COVID-19. International Journal of Information Management, 55, 102170. https://doi.org/10.1016/j.ijinfomgt.2020.102170
Statista. (2020). Global construction expenditure share forecast. Statista. Available online: https://www.statista.com/statistics/561896/construction-spending-share-forecast-worldwide-by-region/ (accessed on 2 January 2024).
Sutherland, E. (2020). The Fourth Industrial Revolution—The case of South Africa. South African Journal of Political Studies. 47(2):233-252.
Tahmasebinia, F., M.E. Sepasgozar, S., Shirowzhan, S., et al. (2020). Criteria development for sustainable construction manufacturing in Construction Industry 4.0. Construction Innovation, 20(3), 379–400. https://doi.org/10.1108/ci-10-2019-0103
Teddlie, C., & Tashakkori, A. (2010). Major issues and controversies in the use of mixed methods in the social and behavioural science. In: Handbook of Mixed Methods in Social and Behavioural Research. Sage.
Thorne, S. (2020). Beyond theming: Making qualitative studies matter. Nursing Inquiry, 27(1). https://doi.org/10.1111/nin.12343
Tjahjono, B., Esplugues, C., Ares, E., et al. (2017). What does Industry 4.0 mean to Supply Chain? Procedia Manufacturing, 13, 1175–1182. https://doi.org/10.1016/j.promfg.2017.09.191
Uleanya, C., & Ke, Y. (2019). Review of Preparedness of Rural African Communities Nexus Formal Education in the Fourth Industrial Revolution. South African Review of Sociology, 50(3–4), 91–103. https://doi.org/10.1080/21528586.2019.1639074
World Bank. (2020a). COVID-19 crisis through a migration lens. World Bank.
World Bank. (2020b). COVID-19 emergency pandemic preparedness and response project. World Bank.
World Health Organisation. (2020). Overview of public health and social measures in the context of COVID-19. Available online: https://www.who.int/publications-detail/overview-of-public-health-and-social-measures-in-the-context-of-covid-19 (accessed on 2 January 2024).
World Health Organisation. (2023). WHO data: WHO health emergencies programme, WHO COVID-19 dashboard. Available online: https://data.who.int/dashboards/covid19/deaths?m49=001&n=c (accessed on 2 January 2024).
Worldometer. (2024). South Africa: Coronavirus cases Worldometer. Available online: https://www.worldometers.info/coronavirus/country/south-africa/ (accessed on 2 January 2024).

Appendix

Semi-structured interview questions

Dear participant,

Request for virtual interview:

Following the global COVID-19 pandemic that has ravished every economic sector economy, including the construction industry, many nations' governments have been brainstorming on the possible ways to curtain this pandemic. Studies have shown that technologies have a significant impact on human capacity building and may mitigate the spread of the virus and build a more resilient construction sector through 4IR technologies. Therefore, this research is titled: Investigating the Impacts of COVID-19 on the Built Environment: The Fourth Industrial Revolution Application's Role Via Unexplored Approach. Specifically, this research is proposed to be achieved through the following objectives:

- To investigate the perceived impacts of COVID-19 pandemic on South Africa's built environment.
- To explore how 4IR technologies can be used to mitigate the spread of COVID-19 and future pandemics within the built environment.

Please note that questions for the virtual interview via Zoom within the stated objectives. Also, your responses will be collated and analysed together with that of other interviewees. This will make up the valued work. All information provided will be handled with the greatest confidentiality.

Hence, your valuable time and other input in answering the questions and contributions will be highly cherished.

Regards.

Yours faithfully,

(Research Coordinator)

Basic questions for the participants

1) Please, for record purposes, what is the name of your organisation?
2) Please, what is your position?
3) How long have you been working?
4) Do you have background knowledge regarding The Fourth Industrial Revolution (4IR) and its use in the South African construction sector?
5) Please, from your experience, can you highlight the perceived negative impacts of COVID-19 pandemic on South Africa's construction industry?
6) Do you think digitalisation of South Africa's construction industry would have mitigated the spread of the virus within the sector?
7) If yes to question 6, how?
8) If no to question 6, why do you think so?
9) How can the 4IR technologies mitigate the spread of COVID-19 within the South African construction industry?
10) Do you think the 4IR technologies can enhance the COVID-19 guidelines regarding physical distancing and large crowd gatherings?
11) As a stakeholder in the industry, what are the perceived hindrances that may hinder construction practitioners from switching to 4IR in their operations?
12) What role do you think the government and other stakeholders can play to support and create the enabling environment to build a more resilient construction sector that can withstand pandemics in the future via 4IR technologies?
13) Do you think 4IR technology is achievable in the South African construction industry?
14) If yes, how can this be achieved?